PARAMETERS OF PNEUMATIC CALIBRATOR OF GRAIN MOTH EGGS FOR *TRICHOGRAMMA* PRODUCTION

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The aim of the work is to increase the efficiency of the biotechnological process of *Trichogramma* production by improving the pneumatic calibrator of grain moth eggs. The trajectory of grain moth eggs movement in horizontal air flow of the pneumatic calibrator, taking into account the equivalent diameter, as well as the initial velocity, is determined. The size and location of containers, height of the separation chamber and valve, and air flow velocity in the calibrator are substantiated. The obtained analytical dependencies allow us to determine the height of vertical channel of the stabilizing nozzle depending on the initial conditions of movement and the equivalent diameter of an egg. The hovering rate of grain moth eggs and conglomerates (depending on the number of eggs in them) is experimentally determined. Optimal values of the structural and technological parameters of the improved pneumatic calibrator (air flow velocity 3.8 m s^{-1}, height of separation chamber 198–199 mm, valve height 26–27 mm) are determined on the basis of the experimental design planning methodology. The probability of selecting large eggs is increasing by 31%.

separation chamber, valve, air flow, trajectory of the movement, egg hovering, probability of egg sampling

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INTRODUCTION

Recently, the increase in crop yields has been ensured by the use of new varieties and the widespread use of mineral fertilizers (B u r a n o v a et al., 2016), pesticides, herbicides, growth stimulants, and increased soil cultivation. This leads to a decrease in soil fertility and crop yields (H a m o u z et al., 2015) and requires periodic revision and increase in the values of normative indicators characterizing food safety. Therefore, there has been a recent increase in the number of enterprises that produce organic products (V l a s i c o v a, N a g l o v a, 2015).

The use of entomological preparations in plant protection leads to an improvement of the phytosanitary situation and an increase in the environmental safety of agricultural products. One of the biological means of plant protection against pests used in agriculture is *Trichogramma*. The qualitative indices of *Trichogramma*, which determine its effectiveness, are: the number of parasitized eggs, search capacity, the regeneration of individuals, the percentage of females, the number of deformed individuals, the life expectancy and fecundity of females.

In *Trichogramma* production technology, it is important to observe temperature regimes and air humidity. The work by O l i v e i r a et al., 2017 analysed the effect of temperature on longevity and the ratio of individuals of the *Trichogramma* species. Studies have shown that the optimum temperature values were in the range of 25 to 28°C. The influence of non-ionizing ultraviolet radiation, as a method of treatment, and its effect on parasitic rate and viability of adult *Trichogramma* individuals was studied, too (E d w i n et al., 2016).

To date, there are several ways to improve the quality of *Trichogramma*, one of which is the use of eggs from natural hosts. Thus, for a long time, in capacity of host eggs for *Trichogramma dendrolimi* production oak silkworm (*Antheraea pernyi*) has been used (W a n g a et al., 2014). The methods for maintaining *Trichogramma* qualitative indicators also include its putting into diapause (the state of physiological inhibition of metabolism and the stopping of the forming processes). In this direction, there was studied the effect of the duration of the light day and the change of temperature regimes on *Trichogramma* quality indices when it's exiting from diapause (R e z n i k, S a m a r t s e v, 2015).

Table 1. Indicators of grain moth populations

Estimation of grain moth breeding regime	Body length of females (mm)	Weight of females (mg)	Average egg volume (mm^3)
Serious violations	< 5.9	< 5.2	< 0.0217
Significant violations	5.9–6.5	5.2–6.8	0.0231 ± 0.0016
Minor violations	6.5–7.1	6.8–8.4	0.0263 ± 0.0016
No violations	> 7.1	> 8.4	> 0.0279

There were studies on the neutralization of biological agents in grain moth eggs using three sterilization methods: UV irradiation, freezing at –15°C, and immersion into a solution of liquid nitrogen. These allow the storage of grain moth eggs for a longer period (St-Onge et al., 2014).

The problem of the allocation of large eggs of grain moth for the production of entomological preparations in the biological plant protection was studied by many scientists and specialists in the 70's and 90's of the last century. In the course of the research, it was found that *Trichogramma* does not infect larger eggs of turnip moth (*Agrotis segetum*) (Grinberg et al., 1989). Such *Trichogramma* infects the eggs of cabbage butterflies (Pierinae) by 20% less and the eggs of European corn borer (*Ostrinia nubilalis*) by 25% less (Grinberg et al., 1986). Experiments at the All-Union Scientific-Research Institute for Plant Protection during breeding the common green lacewing (*Chrysoperla carnea*) on grain moth eggs showed that the larvae bred in the same fodder in identical conditions form cocoons of different sizes and weights. Particularly significant difference is in the weight of the cocoons obtained, when for feeding grain moth eggs of different quality and shelf life, both viable and dead, were used (Makarenko, 1975). Therefore, the improvement of the equipment used to separate grain moth eggs into fractions and using only large eggs of grain moth for *Trichogramma* breeding is relevant as it will increase its effectiveness.

The process of pneumatic separation, especially when it comes to fractionation of grain materials, is well-known. Air purification systems mainly differ in the direction of flow and the additional cleaning system (Gaponyuk, Mosienko, 2012). Besides, the pneumatic separation of mixtures is used in coal industry. The studies aimed at determining the influence of parameters such as: air velocity, conveyor speed, and changes in height between conveyor belts and air nozzles are known (Zheng et al., 2015; Loveikin, Romasevych, 2017).

The results of theoretical studies, in most cases, also describe the movement of grain in the air stream. The physical and mechanical properties of the grain, the air velocity, the initial velocity, and the direction of the particle supply into the air stream influence the grain trajectory in the air flow (Gorial, O'Callaghan, 1991; Saitov et al., 2016). Theoretical studies of the movement of parasitic eggs of grain moth were carried out for conditions of movement in the channels of seeding machines. In this case, the movement of dosed portions of grain moth eggs, which were parasitized by *Trichogramma,* were studied in the airship of aircraft (Adamchuk et al., 2015). Experimental studies of the separation of grain mixtures have shown the complexity of this process (Panasiewicz et al., 2012).

The conducted analysis of methods and technical means of calibration of grain moth eggs showed that the most used devices are those with a pneumatic separation system. For the distribution of grain moth eggs according to the size into three fractions and cleaning them from dust, improving the quality of the stock, as well as the commercial *Trichogramma* culture, a pneumatic calibrator of grain moth eggs is used.

Taking into account the results of well-known studies of the effect of the size of grain moth eggs on the quality of *Trichogramma*, there has been the need to improve the biotechnological process of production of the entomologic biopreparation by means of changes in design, technological parameters, and regimes of pneumatic calibrator, which would allow improving the qualitative indices of the preparation and its efficacy, leading to bigger crops of agricultural products.

Thus, the aim of the work is to increase the efficiency of the biotechnological process of *Trichogramma* production by improving the pneumatic calibrator of grain moth eggs.

MATERIAL AND METHODS

In order to conduct theoretical and experimental studies of the movement of grain moth eggs in the air flow, it is necessary to set the minimum sizes of large eggs. In the works of the Plant Protection Department of the All-Union Scientific-Research Institute for Biological Plant Protection Technologies, it is indicated that according to the lengths of female bodies or their weight, the quality indices of the grain moth populations are divided into 4 groups that correspond to different technologies for their breeding on barley grains (Table 1) (Golyshin, 1983). The length of moth eggs most often varies from 0.48 to 0.63 mm, the width from 0.20 to 0.35 mm. Groups 3 and 4 include eggs wider than 0.28 mm and longer than 0.59 mm.

Table. 2. Values intervals and variation levels of factors

Factor name	Factor levels			Variation intervals
	–1	0	+1	
Air flow velocity (m s^{-1})	3.6	3.8	4.0	0.2
Valve height (mm)	15	25	35	10
Separation chamber height (mm)	180	200	220	20

This made it possible to set the minimum volume of large eggs of the grain moth for the production of *Trichogramma* stock culture, which was 0.0247 mm^3.

For experimental studies, an improved sample of a grain moth egg calibrator (Fig. 1) is being used, consisting of container (1), vibration unit (2), dispenser (3), stabilizing nozzle (4), air-type collector (5), separation chamber (6), cyclone separator (7), aspirator (8) with a filtering element and a valve for controlling the air supply, three containers (9, 10, 11) for grain moth eggs of various fractions, and shutter (12). In the course of the research a certain number of grain moth eggs were taken and separated in a pneumatic calibrator, the parameters and operating modes of which varied according to the plan of the experiment.

To determine the optimal structural parameters and regimes of the pneumatic calibrator of grain moth eggs, a method of multi-factor experiment planning using a three-level matrix of the *D*-optimal Box-Benkin plan was applied. The calculations were made using the Microsoft Office Excel spreadsheet. The intervals of values and variation levels of the investigated factors are given in Table 2.

Heterogeneity of the experimental data variance was assessed by Cochran criterion and adequacy of the obtained regression equation was evaluated by Fisher criterion.

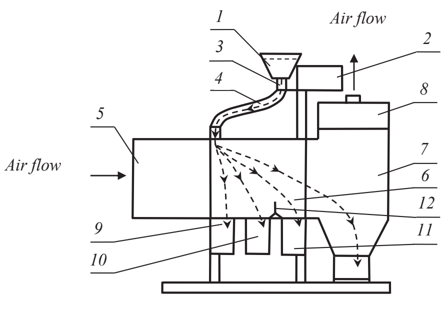

Fig. 1. Scheme of pneumatic calibrator of grain moth eggs
container (1), vibration unit (2), dispenser (3), stabilizing nozzle (4), air-type collector (5), separation chamber (6), cyclone separator (7), aspirator (8) with a filtering element and a valve for controlling the air supply, three containers (9, 10, 11) for grain moth eggs of various fractions, and shutter (12)

In the course of the research, the most significant factors that influence the separation process were considered, namely the air flow velocity υ (m s^{-1}), the height of the valve H_G (mm) and the height of the separation chamber H_C (mm).

The studies were conducted in triple repeats, while measuring the size of random 50 eggs using a stereoscopic microscope MBS-10 of AC 3.850.005 RE type (Production Association 'Rubin', Russia), as shown in Fig. 2 and counting the number of conglomerates in each container at each repetition to determine the composition of the fraction. An anemometer (model YK-2001 TM; dpstar Group, Malaysia) was used to determine the air flow velocity in the air system of the calibrator of grain moth eggs. At the end of the calibration process, each fraction was weighed using electronic laboratory scales (AD-1000; Axis, Poland).

Not to lose the initial sizes and volumes of the grain moth eggs, an experiment was initially performed with the change of all planned regimes and calibrator parameters, and then a number of eggs were taken from each fraction and placed into paper bags stored in the fridge.

Table 3 shows the data and conditions for determining the trajectories of grain moth eggs.

Since grain moth eggs have the form of an ellipsoid, their equivalent diameter was determined based on the volume of a ball the volume of which is equal to the volume of the ellipsoid.

When moving grain moth eggs in the air there is a counteraction to their movement from the side of the air. The coefficient of resistance of the grain moth eggs movement in turbulent air is determined by the aerodynamic air resistance law and is as follows:

$k = 0.5 c r_A F$

where:

c = coefficient of motion resistance of the equivalent ball in air

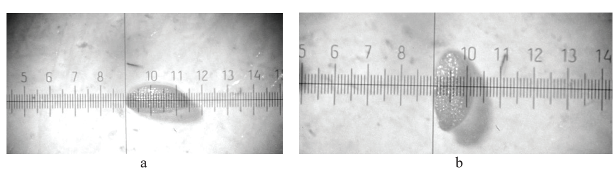

Fig. 2. Measurement of dimensions
a = length, b = width

Table 3. Data used in theoretical studies of grain moth eggs calibration – general initial conditions for eggs flying

Parameters	Unit of measurement	Value		
Egg density	kg m^{-3}	800		
Gravity acceleration	m s^{-2}	9.81		
Coefficient of ball resistance	–	0.4		
Air density	kg m^{-3}	1.23		
Initial speed of eggs	m s^{-1}	0.30		
Air speed	m s^{-1}	5.0		
Initial conditions for conglomerate flying				
Number of eggs in conglomerate		$n = 2$	$n = 4$	$n = 6$
Egg volume	mm^3	0.0558	0.1116	0.1674
Egg weight	mg	0.045	0.089	0.134
Equivalent egg diameter	mm	0.5	0.6	0.7
Coefficient of proportionality *k*	m^{-1}	0.973	0.773	0.675
Initial conditions for large egg flying				
Egg volume	mm^3	0.0279		
Egg weight	mg	0.022		
Equivalent egg diameter	mm	0.4		
Coefficient of proportionality *k*	m^{-1}	1.226		
Initial conditions for small egg flying				
Egg volume	mm^3	0.0217		
Egg weight	mg	0.017		
Equivalent egg diameter	mm	0.3		
Coefficient of proportionality *k*	m^{-1}	1.334		

r_A = air density (kg m^{-3})
F = area of the middle section of the equivalent ball (m^2)
In this study, as a coefficient of proportionality, the ratio of the resistance coefficient of the grain moth eggs movement to the mass of eggs is used.

This value is:

$k = 0.75cr_A(\rho d)^{-1}$

where:
r = density of the grain moth eggs (kg m^{-3})
d = diameter of a grain moth egg represented by an equivalent ball (m)

The aerodynamic index characterizing the movement of grain moth eggs is the rate of hovering in the air stream. This is the critical speed at which the eggs are kept in a hovered condition. If the egg of a grain moth falls into the air stream, the eggs with lower rate of hovering will be blown further. The rate of hovering was determined by means of a device consisting of a pressure mechanism, a hovering chamber and an anemometer, for measuring air velocity. The general view of this device is shown in Fig. 3.

The studies were conducted in the following sequence: grain moth eggs were placed in different fractions in the hovering chamber on a nylon mesh, then the pressure mechanism was turned on and the air supplied to the hovering chamber. By controlling the speed of air with a valve, the moment of hovering of the grain moth eggs in the air flow was determined and the air flow rate at which the grain moth eggs were hovered was measured by the anemometer. Measurements were made in ten repetitions.

RESULTS

After passing the sloping surface of the stabilizing nozzle of the pneumatic calibrator, the grain moth eggs fall into the vertical channel, and after that into the separation chamber. Since eggs and impurities have different aerodynamic properties, they will fall into the chamber of a pneumatic calibrator with its own speed and acceleration. This leads to the need for theoretical studies of the laws that determine the movement of eggs in the vertical channel of the stabilizing nozzle, depending on the structural and technological parameters of the calibrator.

The average value of the density of grain moth eggs was determined on the basis of the fact that 1 g contains 50 000 eggs, and the density was determined depending on the volume of one egg.

Using the known differential equation (Zeldovich, Yaglom, 1982) of the fall of a particle under the action of gravity G, taking into account the resistance of air R, the velocity of grain moth eggs V_E in the vertical channel of the nozzle was determined. After the substitution $V_E = dh/dt$ and the next solution of the differential equation, the height of the vertical channel of the nozzle was found, and determined by Equation (1):

$$h = \frac{1}{2k} \ln \frac{2b + b^2 \exp(2t\sqrt{gk}) + \exp(-2t\sqrt{gk})}{(1+b)^2} \quad (1)$$

where:
V_E = speed of grain moth eggs in the vertical channel of the stabilizing nozzle (m s^{-1})
g = acceleration of gravity (m s^{-2})
t = time of fall (s)
k = coefficient of proportionality (m^{-1})
b = constant value

The constant value is a part of Equation (1), which has the meaning

$$b = \frac{\sqrt{g} + V_0\sqrt{k}}{\sqrt{g} - V_0\sqrt{k}} \quad (2)$$

where:
V_0 = initial rate of grain moth eggs in the vertical channel of the stabilizing nozzle (m s^{-1})

This made it possible to establish the initial conditions for the inclination of the grain moth eggs to the separation chamber of the pneumatic calibrator, namely: the initial speed and acceleration of the eggs, depending on the length of the vertical channel and the equivalent diameter.

Then, after the vertical channel, grain moth eggs fall into the separation chamber, where, under the influence of air flow, they are divided into conglomerates, large and small eggs. Fig. 4 shows the scheme of action of forces while the grain moth eggs move in a horizontal air flow in the coordinate system.

In the analysis of this separation system, the following assumptions have been made: the air flow is flat, its velocity in magnitude and direction is constant at any point in the separation chamber, and the particles and fractions of grain moth eggs move as material bodies, without collisions with each other.

Under the action of airflow and gravity, the egg moves at a velocity V_E. The air is turbulent and the air resistance strength is proportional to the particle velocity in the second degree. Considering the coefficient of proportionality between the strength of the resistance (counteraction to grain moth eggs movement from the side of the air) and the square of the velocity, which includes the mass of the particle, and also that the rate of movement of the particle under the influence of the air flow is determined by the difference between the constant speed of the air flow and the speed of movement of eggs along the axis of abscissa with anchoring to the force scheme on the x and y axes, we can write the system of differential equations of motion in the following way:

$$\begin{cases} \dfrac{d^2x}{dt^2} = \dfrac{3c\rho_{\dot{A}}}{4\rho d}\left(V_{\dot{A}} - V_{EX}\right)^2 = k\left(V_{\dot{A}} - V_{EX}\right)^2 \\ \dfrac{d^2y}{dt^2} = g - \dfrac{3c\rho_A}{4\rho d} V_{EY}{}^2 = g - k\, V_{EY}{}^2. \end{cases} \quad (3)$$

Fig. 3. Measurement of egg fractions hovering rate

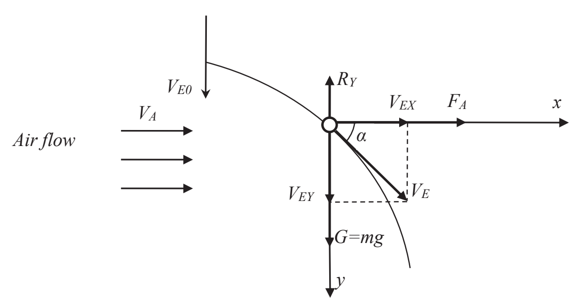

Fig. 4. Scheme of the forces influencing egg movement in horizontal air flow
VE = speed of grain moth eggs in the vertical channel of the stabilizing nozzle
VE0 = initial speed of grain moth eggs in the vertical channel of the stabilizing nozzle
VA = air flow rate
VEX = speed of eggs relative to the x axis
VEY = speed of eggs relative to the y axis
G=mg= egg weight
FA = air flow force
x, y = coordinates of the position of grain moth eggs
Ry = air resistance force, which counteracts of the gravity force

Table 4. Airflow velocities at which grain moth eggs are hovered

Volume of eggs used in research			Air flow speed of grain moth eggs hovering (m s^{-1})	
Egg types		volume (mm^3)	theoretical studies	experimental studies
Conglomerates	of 2 eggs	0.0558	1.9	1.9 ± 0.1
	of 4 eggs	0.1116	2.2	2.2 ± 0.2
	of 6 eggs	0.1674	2.6	2.6 ± 0.2
Large eggs		0.0279	1.8	1.75 ± 0.5
Small eggs		0.0217	1.7	1.65 ± 0.5

where:
x, y = coordinates of the position of grain moth eggs (m)
c = coefficient of ball resistance, which for Reynolds numbers from $1.5 \cdot 10^3$ to $14.5 \cdot 10^3$ (dimensionless value) are approximately the same, and is 0.4
t = time of motion in the separation chamber (s)
ρ_A = air density (kg m^{-3})
ρ = egg density (kg m^{-3})
d = diameter of grain moth egg represented by an equivalent ball (m)
V_A = air flow rate (m s^{-1})
V_{EX} = speed of eggs relative to the x axis (m s^{-1})
V_{EY} = speed of eggs relative to the y axis (m s^{-1})

The exact solution of the system of equations cannot be found, so we will use the method of sequential differentiation, which allows us to obtain an approximate solution of the system of equations (3) in the form of a Taylor series of powers, which, after a series of transformations, has the following form:

$$\begin{cases} x = \dfrac{1}{k}\sum_{n=1}^{n}\dfrac{(kV_A t)^{n+1}}{n+1}(-1)^{n-1}, \\ y = \dfrac{1}{k}\sum_{n=1}^{n}\dfrac{(kV_{E0} t)^{n}}{n}(-1)^{n-1} + \\ \quad + \dfrac{gt^2}{2}\left[1 + \dfrac{1}{1{,}5}\sum_{n=1}^{n}(kV_{E0}t)^n(-1)^n - \dfrac{kgt^2}{6} + \dfrac{4k^2 g V_{E0} t^3}{15}\right]. \end{cases} \tag{4}$$

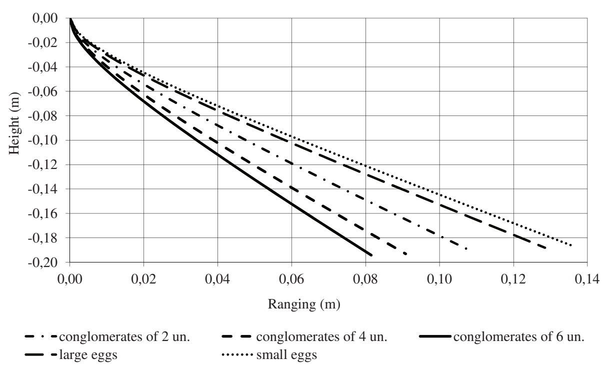

Fig. 5. Estimated trajectories of conglomerates and grain moth eggs movement in air stream (Equation 4)

where:
V_{E0} = initial speed of eggs movement in the separation chamber (m s^{-1})

The obtained equations allow us to establish the trajectory of the movement of grain moth eggs in the separation chamber, depending on the initial velocity, the movement time in the separation chamber, the equivalent diameter of grain moth eggs and the speed of the air flow. The trajectory of grain moth eggs in the separation chamber of the pneumatic calibrator, depending on their volume at an air speed of 5 m s^{-1} and an initial velocity of 0.3 m s^{-1}, is given in Fig. 5.

Thus, studies have confirmed that a slight difference in weight leads to an almost identical trajectory of the movement of grain moth eggs in the air stream, except for conglomerates. The large and small eggs in the air flow fly quite tightly to each other and therefore it is necessary to establish a valve between the second and third containers, which will provide an opportunity to improve the efficiency of their separation.

The results of theoretical studies listed above (Fig. 5) and preliminary experimental studies conducted by the present authors (M a r u s , G o l u b , 2008) have shown that the quality of the separation process is most influenced by the speed of the air flow, the valve height and the height of the pneumatic calibrator separation chamber. Constant were the following structural and technological parameters of the calibrator: the angle of the stabilizing nozzle of 20° and the length of the receiving containers: the first – 110 mm, the second – 30 mm, and the third – 90 mm.

Besides, the velocity of airflow at which hovering of grain moth eggs takes place – V_S (m s^{-1}) (Table 4) was determined both in theoretical and experimental studies.

The results of measuring made it possible to determine the probability of selecting large grain moth eggs for the second calibrator container the values of which are shown in Table 5. Cochran criterion attained the value of $G = 0.08$ and was less than its table value $G_T = 0.335$ at a confidence level of 95%. This indicates the heterogeneity of variance of the experimental data.

After the multivariate experiment, an addiction was established to determine the probability of selecting large eggs in the form of a regression equation that has the form:

Table 5. Numerical values of factors and probability of selecting large grain moth eggs for the second calibrator container

Experiment No.	Factor names			Probability of selecting large eggs (%)
	air flow velocity (m s^{-1})	valve height (mm)	separation chamber height (mm)	
1	4.0	35	200	49
2	3.6	15	200	51
3	4.0	15	200	41
4	3.6	35	200	37
5	4.0	25	220	45
6	3.6	25	180	49
7	4.0	25	180	48
8	3.6	25	220	40
9	3.8	35	220	50
10	3.8	15	180	39
11	3.8	35	180	50
12	3.8	15	220	43
13	3.8	25	200	57
14	3.8	25	200	54
15	3.8	25	200	62

$$P = -2428{,}9 + 1124{,}439V_A - 5{,}7362H_G + 4{,}1715H_C - \\ -166{,}1294V_A^2 - 0{,}0665H_G^2 - 0{,}0138H_C^2 + \\ + 2{,}6882V_AH_G + 0{,}375V_AH_C - 0{,}005H_GH_C, \quad (5)$$

where:
P = probability of selection of large eggs of grain moth (%)
H_G = height of the valve (mm)
H_C = height of the separation chamber (mm)
V_A = air flow rate (m s^{-1})

The significance of the coefficients of the regression equation was tested according to Student's criterion by 90% confidence level. The values of the coefficients of the equation exceeded the confidence interval, which was determined by multiplying of the *t*-criterion of Student and the standard deviation for each coefficient of the regression equation, and therefore it was concluded that the coefficients of the obtained regression equation are significant only in the ranges of values of the factors listed in Table 2. This is also due to the fact that the conduct of previous studies allowed the rejection of the factors of the experiment which were not significant in relation to the probability of the selection of large eggs of the grain moth.

Fisher criterion at a confidence level of 95% amounted to $F = 2.29$ and was less than its table value $F_T = 2.53$, indicating the adequacy of the obtained regression equation.

The analysis of the obtained equation has shown that the probability of selecting large eggs of grain moth falling into the second container has the maximum value of 58% (Fig. 6) at the air flow rate in the range of 3.75 to 3.85 m s^{-1} and the height of the valve of 25 mm. When reducing the speed of air flow, part of large eggs falls into the first container, and part of the small ones – to the second. With an increase in the air flow rate, part of the conglomerates falls into the second container, and part of the large eggs – to the third.

The optimum height of the calibrator separation chamber is in the range from 192 to 202 mm (Fig. 7), at an air flow rate of 3.8 m s^{-1}, since the probability of selecting large eggs thus is maximal. Increasing the height of the separation chamber leads to the fact that part of the conglomerates that had to reach the first container, have time to reach the second one. Reducing the height of the separation chamber leads to a decrease in the likelihood of large eggs selection. This is explained by the fact that small eggs of the grain moth, which are close to the large ones, do not have time to fly to the third container and fall into the second one, reducing the quality of separation.

The dependence of the probability of selecting large eggs on the height of the valve and the height of the separation chamber is shown in Fig. 8. The optimal height of the valve at the height of the separation chamber of 200 mm is in the range of 23 to 28 mm. Reducing the height of the valve leads to the fact that a part of the large eggs reaches the third container, thus changing the total share of them in the second container. Increasing the valve height leads to the fact that the eggs, which were close in size to large ones, cannot get into the third container, which results in a lower probability of the selection of large eggs in the second container.

A comparison of theoretical and experimental studies (Fig. 9) showed that in the first container there should be conglomerates with the probability of their selection 78%; part of them flew into the second container and an insignificant part – to the third one. In the second container, where there should be large eggs of grain moth with the probability of their selection about 58%, also conglomerates (18%) and small eggs (26%) occurred.

In the third container, where small eggs were to be found with the probability of their selection about 80%, there were also conglomerates, and about 18% of large eggs. The rejection of the results of experimental studies from the theoretical is due to assumptions made in theoretical studies.

The conducted researches allowed to establish optimal structural and technological parameters of the pneumatic calibrator, and to improve the quality of the separation of grain moth eggs.

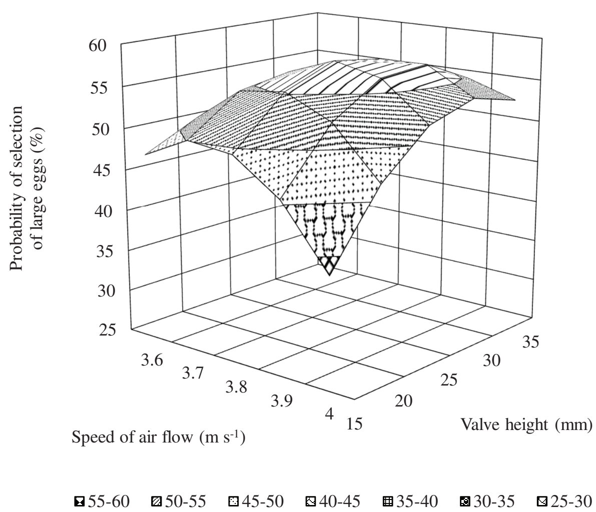

Fig. 6. Dependence of selection probability of large eggs on air flow speed and valve height (separation chamber height = 200 mm)

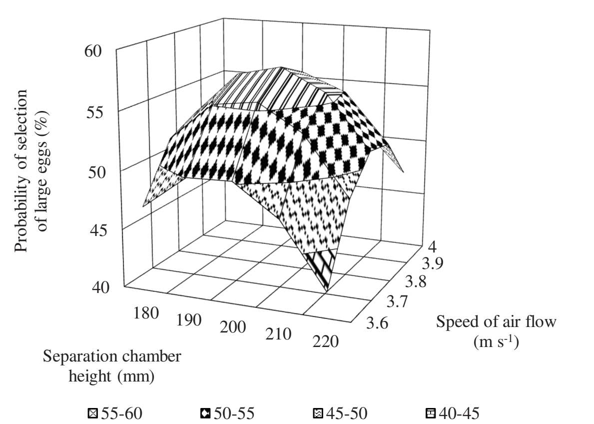

Fig. 7. Dependence of selection probability of large eggs on separation chamber height and air flow rate (valve height = 25 mm)

DISCUSSION

The positive influence of the phytophages eggs size on the quality indices of *Trichogramma* has been described in the studies of specialists in the biological protection of plants. This became the basis for justifying the importance of the operation for the selection of large eggs of grain moth, especially in the production of *Trichogramma*. Bondarenko (1981) noted that small entomophages appear on small grain moth eggs. Their use reduces the effectiveness of pest control, because they are not able to infect larger eggs phytophages. Telenga, Shchepetylnikova (1949) argue that the egg size of the grain moth affects the *Trichogramma* fecundity. In the studies by Medoni et al. (1980), among other indicators, the effect of large eggs of grain moth on the viability of the *Trichogramma* is described. These results confirmed the necessity of using a grain moth eggs separation on fractions in the *Trichogramma* production technology. Marus, Golub (2008) determined the optimal method for selecting large eggs of grain moth using pneumatic, centrifugal and electrostatic separation methods. The results of these studies have shown that the highest percentage of selection of large eggs of grain moth was when using a pneumatic calibrator. The

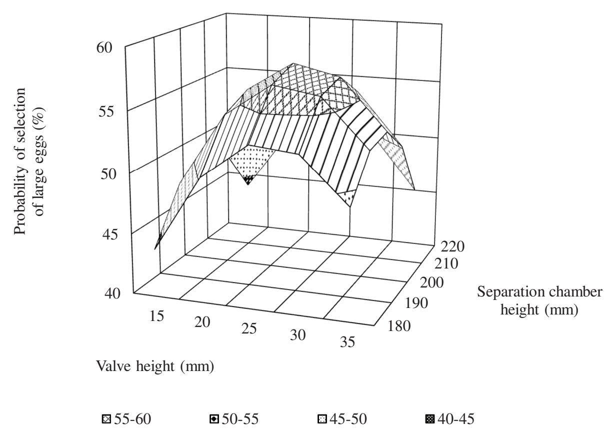

Fig. 8. Dependence of selection probability of large eggs on valve height and separation chamber height (air flow speed = 3.8 m s–1)

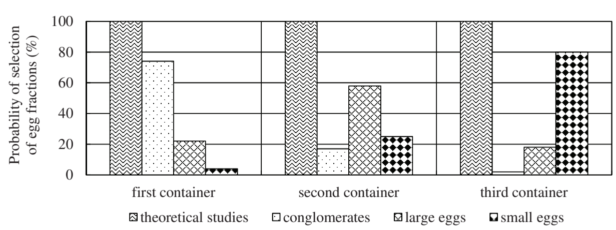

Fig. 9. Diagram comparing theoretical and experimental studies of grain moth eggs distribution in calibrator containers

Engineering and Technology Institute 'Bioengineering' National Academy of Agrarian Sciences of Ukraine (Odessa region, Ukraine) has developed a design of a pneumatic calibrator of grain moth eggs, which is used in the laboratory of biological methods of plant protection of the National University of Life and Environmental Sciences of Ukraine. However, a wider use of the pneumatic calibrator of grain moth eggs in the technology of *Trichogramma* production is missing at the moment. In our opinion the reason for this is the absence of scientifically substantiated parameters and operating modes of the pneumatic calibrator of grain moth eggs.

The quality check of the pneumatic calibrator was carried out on a mixture of grain moth eggs, consisting of 28% conglomerates, 34% large eggs and 38% small eggs. After calibration, from the total of 28% conglomerates 17% fell into the first container, and the other part – into the second and third containers. In the second container, where big eggs were to come, there were found 16% out of 34%, a small part was in the first container – 4% and in the third one – 14%. Talking about the small eggs of the grain moth, into the third container fell 24%, and 14% fell into other fractions (M a r u s , 2008). Thus, the process of separating grain moth eggs in the air stream required additional research to rationale the parameters of the calibrator.

The research results application on the parameters of grain moth eggs calibrator can increase the probability of selecting large eggs by 22%, which improves the quality and efficiency of *Trichogramma*. These results were used to improve the biotechnological process for the production of the entomological preparation of *Trichogramma* and to develop a modular set of technological equipment for industrial *Trichogramma* breeding at the Engineering and Technology Institute 'Bioengineering' National Academy of Agrarian Sciences of Ukraine (Odessa region, Ukraine).

Further research in the field of biological protection of plants using *Trichogramma* is advisable to direct to the determination of the grain moth eggs size effect on the quality of *Trichogramma*. The indicators to be studied include: the fecundity and the percentage of females in a batch of *Trichogramma*, the longevity of individuals, the percentage of deformed individuals and the regeneration, the searching capacity of *Trichogramma* and the level of grain moth eggs parasitized by *Trichogramma* for several generations.

CONCLUSION

The obtained analytical dependencies allow to determine the height of the vertical channel of the stabilizing nozzle depending on the initial conditions of movement and the equivalent diameter of an egg, as well as the speed of grain moth eggs in the horizontal air flow of the separation chamber, which made it possible to determine the trajectory of the eggs, on the basis of which to set the calibrator parameters that affect the quality of separation, in particular the dimensions and location of the containers, the height of the separation chamber and the valve, as well as the air flow velocity.

The rate of hovering of grain moth eggs was experimentally determined – for small ones: 1.6–1.7 m s^{-1}, and for large ones: 1.7–1.8 m s^{-1}. The rate of hovering for conglomerates (depending on the number of involved eggs) was: for conglomerates of two eggs – 1.8–2.0 m s^{-1}; of four eggs – 2.0–2.4 m s^{-1}; of six eggs – 2.4–2.8 m s^{-1}.

The optimal values of the structural and technological parameters of the improved pneumatic calibrator, namely, the air flow velocity of 3.8 m s^{-1}, the height of the separation chamber 198–199 mm, and the valve height 26–27 mm, were determined on the basis of the experimental design planning methodology. The probability of selecting large eggs in the second container of the calibrator was 58%, which is by 31% more when compared to the base design. Experimental studies have shown that the variation in the probability of selection from the maximum theoretical value is: for conglomerates – 22%, for large eggs – 42%, for small eggs – 20%.

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